# 1.0 Calculation of Human Health Risk-Based Benzo(a)pyrene-equivalent Threshold Concentrations for cPAHs – Basis for Revised cPAH Cleanup Levels and Target Tissue Levels

This section presents the calculation of human health risk-based threshold concentrations (RBTCs) for cPAHs, expressed as a benzo(a)pyrene-equivalent concentration in sediment and clam tissue, assuming a target excess cancer risk of $1 \times 10^{-6}$. The revised RBTCs were calculated using the exposure assumptions and values from Section B.3.2 of the Lower Duwamish Waterway (LDW) Human Health Risk Assessment (HHRA, LDWG 2005), and errata (LDWG, 2009). When RBTCs are greater than established background concentrations, they are the basis for the revised cleanup levels in this Explanation of Significant Differences (ESD).

RBTCs associated with Remedial Action Objective 2, direct contact with sediment, were calculated to account for incidental ingestion and dermal exposures. These values were then combined to derive a single RBTC protective of both exposure pathways as follows:

$$RBTC_{sed} = \cfrac{1}{\cfrac{1}{RBTC_{sed-Ingestion}} + \cfrac{1}{RBTC_{sed-Dermal}}}$$

## 1.1 Netfishing/Clamming

RBTCs protective of the adult tribal netfishing and clamming RME scenarios were calculated using the exposure assumptions described in Tables B.3-15 and 16, and B.3-23 and 24 of the HHRA, respectively.

RBTCs protective of incidental ingestion of sediment were calculated using the following equation:

$$RBTC_{sed\text{-}ingestion} = \frac{TR \times BW \times AT_c}{EF \times ED \times CSF \times IR_{sed} \times CF_{kg/mg} \times CF_{mg/\mu g}}$$

RBTCs for dermal contact with sediment were calculated using the following equation:

$$RBTC_{sed-dermal} = \frac{TR \times AT_c \times BW_a}{EF \times ED \times CSF \times SA \times AF \times ABS \times CF_{kg/mg} \times CF_{mg/\mu g}}$$

| | | |
|---|---|---|
| RBTC$_{sed\text{-}ingestion}$ | = | risk-based threshold concentration in sediment (µg/kg) |
| RBTC$_{sed\text{-}dermal}$ | = | risk-based threshold concentration in sediment (µg/kg) |
| IR$_{sed}$ | = | incidental sediment ingestion rate (mg/day) |
| EF | = | exposure frequency (days/year) |
| ED | = | exposure duration (years) |

| | | |
|---|---|---|
| BW$_a$ | = | body weight – adult (kg) |
| ABS | = | dermal absorption factor |
| SA | = | exposed skin surface area (cm$^2$) |
| AF | = | soil-to-skin adherence factor (mg/cm$^2$) |
| AT$_c$ | = | averaging time (days) |
| CF$_{kg/mg}$ | = | conversion factor – kg/mg (0.000001) |
| CF$_{mg/\mu g}$ | = | conversion factor – mg/$\mu$g (0.001) |
| CSF | = | cancer slope factor (mg/kg-day)$^{-1}$ |
| TR | = | target excess cancer risk |

Exposure assumptions are shown in Table 1.

## 1.2    Beach Play

As discussed in Section 8.5.1.1 of the HHRA, EPA guidance (EPA 2005) notes that exposures to a carcinogen in early life may result in higher lifetime cancer risks than a comparable duration adult exposure, and recommends the application of age-dependent adjustment factors of 10 and 3, respectively, for exposures occurring before 2 years of age and from ages 2 through 6 when a carcinogen is known to cause cancer through a mutagenic mode of action. RBTCs for the RME beach-play scenario were calculated using the exposure assumptions presented in Tables B.3-19 and 20 of the HHRA.

The RBTC based on incidental ingestion of sediment was calculated using the following equation:

$$RBTC_{sed-ingestion} = \frac{TR \times AT_c}{CSF \times IR_{beach-adj} \times CF_{kg/mg} \times CF_{mg/\mu g}}$$

Where:

$$IR_{beach-adj} = \begin{pmatrix} \dfrac{(EF_{0-1} \times ED_{0-1} \times IR_{sed-beach}) \times 10}{BW_{0-1}} + \dfrac{(EF_{0-1} \times ED_{1-2} \times IR_{sed-beach}) \times 10}{BW_{1-2}} + \dfrac{(EF_{0-1} \times ED_{2-3} \times IR_{sed-beach}) \times 3}{BW_{2-3}} \\ + \dfrac{(EF_{0-1} \times ED_{3-4} \times IR_{sed-beach}) \times 3}{BW_{3-4}} + \dfrac{(EF_{0-1} \times ED_{4-5} \times IR_{sed-beach}) \times 3}{BW_{4-5}} + \dfrac{(EF_{0-1} \times ED_{5-6} \times IR_{sed-beach}) \times 3}{BW_{5-6}} \end{pmatrix}$$

RBTCs for cPAHs based on dermal exposure to sediments was calculated using the following equation:

$$RBTC_{sed-dermal} = \frac{TR \times AT}{CSF \times DF_{beach-adj} \times ABS \times CF_{kg/mg} \times CF_{mg/\mu g}}$$

Where

$$DF_{beach-adj} = \begin{pmatrix} \dfrac{EF_{beach} \times ED_{0-1} \times AF_{beach} \times SA_{0-1} \times 10}{BW_{0-1}} + \dfrac{EF_{beach} \times ED_{1-2} \times AF_{beach} \times SA_{1-2} \times 10}{BW_{1-2}} + \dfrac{EF_{beach} \times ED_{2-3} \times AF_{beach} \times SA_{3-4} \times 3}{BW_{2-3}} \\[2em] + \dfrac{EF_{beach} \times ED_{3-4} \times AF_{beach} \times SA_{3-4} \times 3}{BW_{3-4}} + \dfrac{EF_{beach} \times ED_{4-5} \times AF_{beach} \times SA_{4-5} \times 3}{BW_{4-5}} + \dfrac{EF_{beach} \times ED_{5-6} \times AF_{beach} \times SA_{5-6} \times 3}{BW_{5-6}} \end{pmatrix}$$

and:

| | | |
|---|---|---|
| $RBTC_{sed-ingestion}$ | = | risk-based threshold concentration in sediment (µg/kg) |
| $RBTC_{sed-dermal}$ | = | risk-based threshold concentration in sediment (µg/kg) |
| $IR_{beach\_adj}$ | = | incidental sediment ingestion – beach play (mg/kg) |
| $DF_{beach\_adj}$ | = | dermal sediment contact factor – beach play (mg/kg) |
| $EF_{beach}$ | = | exposure frequency – beach play (days/year) |
| ABS | = | dermal absorption factor |
| $AF_{beach}$ | = | soil-to-skin adherence factor – beach play (mg/cm$^2$) |
| $ED_{0-1}$ | = | exposure duration age 0-1 (years) |
| $ED_{1-2}$ | = | exposure duration age 1-2 (years) |
| $ED_{2-3}$ | = | exposure duration age 2-3 (years) |
| $ED_{3-4}$ | = | exposure duration age 3-4 (years) |
| $ED_{4-5}$ | = | exposure duration age 4-5 (years) |
| $ED_{5-6}$ | = | exposure duration age 5-6 (years) |
| $SA_{0-1}$ | = | exposed skin surface area age 0-1 (cm$^2$) |
| $SA_{1-2}$ | = | exposed skin surface area age 1-2 (cm$^2$) |
| $SA_{2-3}$ | = | exposed skin surface area age 2-3 (cm$^2$) |
| $SA_{3-4}$ | = | exposed skin surface area age 3-4 (cm$^2$) |
| $SA_{4-5}$ | = | exposed skin surface area age 4-5 (cm$^2$) |
| $SA_{5-6}$ | = | exposed skin surface area age 5-6 (cm$^2$) |
| $BW_{0-1}$ | = | body weight age 0-1 (kg) |
| $BW_{1-2}$ | = | body weight age 1-2 (kg) |
| $BW_{2-3}$ | = | body weight age 2-3 (kg) |
| $BW_{3-4}$ | = | body weight age 3-4 (kg) |
| $BW_{4-5}$ | = | body weight age 4-5 (kg) |
| $BW_{5-6}$ | = | body weight age 5-6 (kg) |
| $CF_{kg/mg}$ | = | conversion factor – kg/mg (0.000001) |
| $CF_{mg/µg}$ | = | conversion factor – mg/µg (0.001) |
| $AT_c$ | = | averaging time (days) |
| TR | = | target excess cancer risk |
| CSF | = | cancer slope factor (mg/kg-day)$^{-1}$ |
| TR | = | target cancer risk |

Exposure assumptions are shown in Table 1. RBTCs for cPAHs in sediment are shown in Table 2.

## 1.3 Clam Tissue Risk-Based Concentrations

As discussed in the LDW ROD Section 8.2.3, fish and shellfish Target Tissue Levels (TTLs) were included to measure progress toward achieving RAOs 1 and 4. The TTL for cPAHs is a risk-based concentration in clam tissue, calculated based on tribal clam consumption rates.

The RBTC based on consumption of clams by adults was calculated using the following equation:

$$RBTC_{clams} = \frac{TR \times BW_a \times AT_c}{ED_a \times EF_{cc} \times CSF \times CR_{a-cc} \times CF_{kg/mg} \times CF_{mg/\mu g} \times CF_{mg/g}}$$

The RBTC based on consumption of clams by children was calculated using the following equation:

$$RBTC_{clams} = \frac{TR \times AT_c}{CSF \times CR_{cc-c-adj} \times CF_{kg/mg} \times CF_{mg/\mu g} \times CF_{mg/g}}$$

where:

$$CR_{cc-c-adj} = \left( \begin{array}{c} \dfrac{EF_{cc} \times ED_{0-1} \times CR_{cc-c} \times 10}{BW_{0-1}} + \dfrac{EF_{cc} \times ED_{1-2} \times CR_{cc-c} \times 10}{BW_{1-2}} + \dfrac{EF_{cc} \times ED_{2-3} \times_c \times CR_{cc-c} \times 3}{BW_{2-3}} \\ + \dfrac{EF_{cc} \times ED_{3-4} \times CR_{cc-c} \times 3}{BW_{3-4}} + \dfrac{EF_{cc} \times ED_{4-5} \times CR_{cc-c} \times 3}{BW_{4-5}} + \dfrac{EF_{cc} \times ED_{5-6} \times CR_{cc-c} \times 3}{BW_{5-6}} \end{array} \right)$$

and:

| | | |
|---|---|---|
| $RBTC_{clams}$ | = | risk-based concentration in clams (µg/kg, wet-weight) |
| $CR_{c-cc}$ | = | consumption rate clams – child (g/day, wet-weight) |
| $CR_{a-cc}$ | = | consumption rate – clams – adult (g/day, wet-weight) |
| $CR_{cc-c-adj}$ | = | consumption rate clams – age-adjusted (g/kg) |
| $EF_{cc}$ | = | exposure frequency clam consumption (days/year) |
| $ED_c$ | = | exposure duration – child (years) |
| $ED_a$ | = | exposure duration – adult (years) |
| $ED_{0-1}$ | = | exposure duration age 0-1 (years) |
| $ED_{1-2}$ | = | exposure duration age 1-2 (years) |
| $ED_{2-3}$ | = | exposure duration age 2-3 (years) |
| $ED_{3-4}$ | = | exposure duration age 3-4 (years) |
| $ED_{4-5}$ | = | exposure duration age 4-5 (years) |
| $ED_{5-6}$ | = | exposure duration age 5-6 (years) |
| $BW_{0-1}$ | = | body weight age 0-1 (kg) |
| $BW_{1-2}$ | = | body weight age 1-2 (kg) |
| $BW_{2-3}$ | = | body weight age 2-3 (kg) |
| $BW_{3-4}$ | = | body weight age 3-4 (kg) |
| $BW_{4-5}$ | = | body weight age 4-5 (kg) |

$BW_{5-6}$ = body weight age 5-6 (kg)
$BW_a$ = body weight – adult (kg)
$CF_{kg/mg}$ = conversion factor – kg/mg (0.000001)
$CF_{mg/\mu g}$ = conversion factor – mg/µg (0.001)
$CF_{mg/g}$ = conversion factor – mg/g (1,000)
$AT_c$ = averaging time, cancer (days)
CSF = cancer slope factor $(mg/kg\text{-}day)^{-1}$
TR = target cancer risk

The exposure assumptions are shown in Table 1. Revised RBTCs for cPAHs are shown in Table 3. Consistent with selection of the TTL in the ROD, the more stringent value is the basis for the TTL in the ESD.

## 1.4 Risk-Based Threshold Concentrations for Benzo(a)pyrene Based on a Non-Cancer Endpoint

The 2014 ROD did not provide cleanup goals based on noncancer effects of cPAHs because no noncancer reference doses were available at that time. However, as part of the 2017 revised cancer assessment for benzo(a)pyrene, EPA established a reference dose (RfD) for benzo(a)pyrene of 0.003 mg/kg-day. Unlike the cancer slope factor, which may be applied to the other cPAHs through the application of Potency Equivalency Factors, the RfD is only applicable to benzo(a)pyrene. In order to assess whether the revised cleanup goals based on a cancer endpoint would be protective of non-cancer effects associated with benzo(a)pyrene, EPA conducted a screening assessment using its Regional Screening Levels (RSLs, EPA 2020) as a basis for such a comparison. The RSLs are risk-based screening levels, regularly updated using the latest toxicity values and default exposure assumptions. Because cancer risk and noncancer hazard are directly proportional to the degree of exposure and the toxicity of a chemical, a comparison of RSLs calculated based on cancer and noncancer endpoints can be used to determine which value is more protective. Assuming default exposure assumptions for incidental ingestion and dermal exposure associated with residential land use and a target cancer risk of $1 \times 10^{-6}$ or noncancer hazard quotient of 1, the RSLs are 0.1 mg/kg and 18 mg/kg, respectively. Thus, cleanup goals calculated in the ESD based on the noncancer RfD for benzo(a)pyrene would be greater than those based on a cancer risk of $1 \times 10^{-6}$ by more than two orders of magnitude.

## References

EPA 2005. Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens. Risk Assessment Forum. Washington, D.C. EPA/630/R-03/003F. March 2005.

EPA 2020, Regional Screening Levels, May 2020 update. https://www.epa.gov/risk/regional-screening-levels-rsls

LDWG. 2005. Lower Duwamish Waterway Remedial Investigation, Remedial Investigation Report. Appendix B: Baseline Human Health Risk Assessment

LDWG. 2007. Lower Duwamish Waterway Remedial Investigation, Remedial Investigation Report. Appendix B: Baseline Human Health Risk Assessment.  Errata: Adjustment to Tulalip Tribes Seafood Consumption Rates and the Impact on Risk Estimates.

**Table 1 Human Health Exposure Values**

| Symbol | Description | Units | Value |
|---|---|---|---|
| ABS | Dermal absorption factor | unitless | 0.13 |
| $AF_{\_beach}$ | Soil to skin adherence factor- beach play | mg/cm$^2$-event | 0.2 |
| $AF_{\_clam}$ | Soil to skin adherence factor- clamming | mg/cm$^2$- event | 0.2 |
| $AF_{net}$ | Soil to skin adherence factor- netfishing | mg/cm$^2$- event | 0.2 |
| $AT_c$ | Averaging time - cancer | days | 25,550 |
| $BW_{0-!}$ | Body weight <1 yr | kg | 9.1 |
| $BW_{1-2}$ | Body weight 1-2 yrs | kg | 11.3 |
| $BW_{2-3}$ | Body weight 2-3 yrs | kg | 13.3 |
| $BW_{3-4}$ | Body weight 3-4 yrs | kg | 15.3 |
| $BW_{4-5}$ | Body weight 4-5 yrs | kg | 17.4 |
| $BW_{5-6}$ | Body weight 5-6 yrs | kg | 19.7 |
| $BW_a$ | Body weight - adult | kg | 81.8 |
| CF | Conversion factor - kg/mg | kg/mg | 0.000001 |
| CF | Conversion factor - mg/µg | mg/µg | 0.001 |
| CF | Conversion factor - mg/g | mg/g | 1000 |
| $CR_{cc\_a}$ | Clam consumption rate - adult | g/day | 43.4 |
| $CR_{cc\_c}$ | Clam consumption rate - child | g/day | 17.4 |
| $CR_{cc\_c\_adj}$ | Age-adjusted clam consumption factor | g/kg | 15047 |
| $DF_{beach\_adj}$ | Age-adjusted dermal factor | mg/kg | 62141 |
| $ED_{\_clam}$ | Exposure duration – clamming | years | 64 |
| $ED_{a-cc}$ | Exposure duration – clam consumption- adult | years | 70 |
| $ED_{0-1}$ | Exposure duration <1 yr– beach play | years | 1 |
| $ED_{1-2}$ | Exposure duration 1-2 yrs– beach play | years | 1 |
| $ED_{2-3}$ | Exposure duration 2-3 yrs– beach play | years | 1 |
| $ED_{3-4}$ | Exposure duration 3-4 yrs– beach play | years | 1 |
| $ED_{4-5}$ | Exposure duration 4-5 yrs– beach play | years | 1 |
| $ED_{5-6}$ | Exposure duration 5-6 yrs– beach play | years | 1 |
| $ED_{net}$ | Exposure duration - netfishing | years | 44 |
| $EF_{\_beach}$ | Exposure frequency - beach play | days/yr | 65 |
| $EF_{\_clam}$ | Exposure frequency - clamming | days/yr | 120 |
| $EF_{cc}$ | Exposure frequency – clam consumption | days/yr | 365 |
| $EF_{net}$ | Exposure frequency - netfishing | days/yr | 119 |
| $IR_{\_sed\_clam}$ | Incidental sediment ingestion rate - clamming | mg/day | 100 |
| $IR_{beach\_adj}$ | Age-adjusted sediment ingestion rate | mg/kg | 35493 |
| $IR_{sed-beach}$ | Incidental sediment ingestion rate | mg/day | 200 |
| $IR_{sed-net}$ | Incidental ingestion rate | mg/day | 50 |
| $SA_{\_clam}$ | Skin surface area exposed – adult - clamming | cm$^2$ | 6,040 |

**Table 1 Human Health Exposure Values**

| Symbol | Description | Units | Value |
|--------|-------------|-------|-------|
| $SA_{0-1}$ | Skin surface area < 1 yr | $cm^2$ | 1,330 |
| $SA_{1-2}$ | Skin surface area 1-2 yrs | $cm^2$ | 1,750 |
| $SA_{2-3}$ | Skin surface area 2-3 yrs | $cm^2$ | 2,069 |
| $SA_{3-4}$ | Skin surface area 3-4 yrs | $cm^2$ | 2,298 |
| $SA_{4-5}$ | Skin surface area 4-5 yrs | $cm^2$ | 2,515 |
| $SA_{5-6}$ | Skin surface area 5-6 yrs | $cm^2$ | 2,751 |
| $SA_{net}$ | Skin surface area exposed – adult - netfishing | $cm^2$ | 3,600 |
| CSF | Cancer slope factor - benzo(a)pyrene | $(mg/kg\text{-}day)^{-1}$ | 1 |
| TR | Target cancer risk | unitless | 1E-06 |

**Table 2: Risk-Based BaP-equivalent Threshold Concentrations in Sediment**

| Scenario | | Ingestion (µg/kg dw) | Dermal (µg/kg dw) | Total (µg/kg dw) |
|----------|---|----------------------|-------------------|------------------|
| Netfishing | | 7,983 | 4,265 | 2,780 |
| Clamming | | 2,721 | 1,733 | 1,059 |
| Beach Play | | 720 | 3,163 | 586 |

**Table 3: Risk-Based BaP-equivalent Threshold Concentrations in Clam Tissue**

| Child (µg/kg ww) | | Adult (µg/kg ww) |
|------------------|---|------------------|
| 1.5 | | 1.9 |